

1 Introduction

Extensive research has shown that tropical forests regressed considerably and fragmented during the last glacial maximum, dating from about 20 000 BP (Maley 1987, 1996) which led to the extension of ice at high latitudes in both hemispheres. The subsequent phase of maximal forest extension began about 10 000 BP, simultaneously with the phase of global warming corresponding to the Holocene period. Until very recently, numerous specialists thought that the Central African forests (Figure 1) had not suffered major disturbance during the Holocene until the beginning of the twentieth century, and the current period of intensive forest exploitation. Yet during the last decade of the twentieth century, geological and palynological research conducted on lake sediments from several sites has shown that about 2500 BP the Central African forest experienced catastrophic destruction with a major extension of the savannas (Maley and Brenac 1998a).

This article presents the principal data concerning the event, and considers its significance for vegetation development both during the Holocene and up to the present day. Then, taking the example of two species, it will show how their history has been profoundly affected by this event. Finally, it will try to contextualise the event in the regional and global paleo-climatic framework by comparing it with earlier phases of forest regression.

2 Variations in the vegetation of Central Africa during the Holocene

Only one site in Atlantic Central Africa: lake Barombi Mbo in west Cameroon, provides a detailed pollen record, which dates back beyond 28 000 years BP (Maley and Brenac 1998a) (Figure 2).

The records from other sites begin during the Holocene. Only at Barombi Mbo has it been possible to examine the installation of the forest environment at the beginning of the Holocene, and subsequent variation in the principal tree taxa (Maley and Brenac 1998a). This variation reveals pseudo-periods of about 2,000 to 2,500 years for several tree taxa typical of mature (or 'primary') forest (Figure 3a). A

A Catastrophic Destruction of African Forests about 2,500 Years Ago Still Exerts a Major Influence on Present Vegetation Formations

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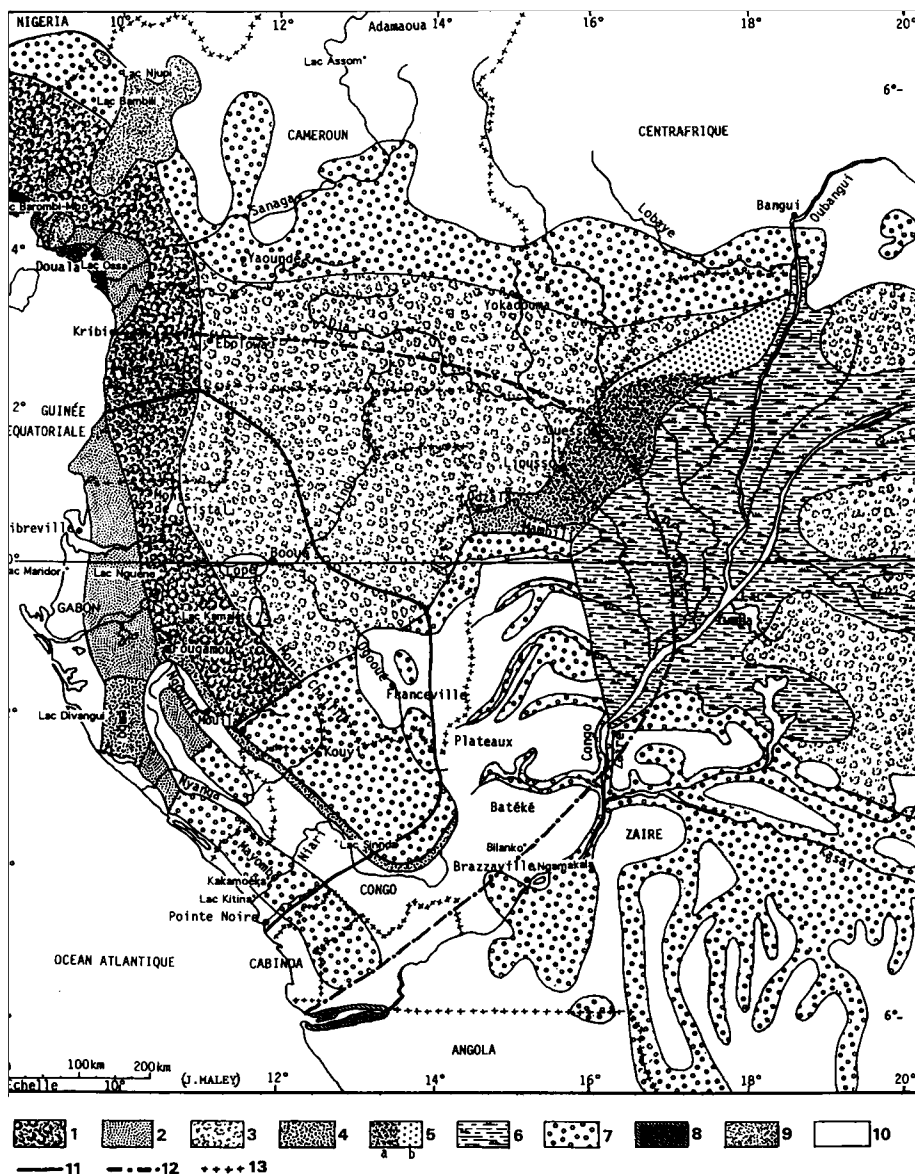


Figure 1: Schematic map of present vegetation in Central Africa (Maley 1990)

(1) Biafran and Gabonese evergreen forests with numerous *Cesalpiniaceae*, (2) Atlantic coastal forests with *Sacoglottis gabonensis* and *Lophira alata* in Cameroon, with the addition of *Aucoumea klaineana* (Okoumé) in Gabon (see 11). The boundary between 1 and 2 is irregular and often progressive, (3) Forests of Congolese type, with mixture of evergreen and semi-deciduous formations, (4) Open canopy forests with a dense ground cover dominated by large Monocotyledons belonging to *Marantaceae* and *Zingiberaceae*, (5) (a) Mixture of types 4 and 5b; (b) Evergreen forests with a high canopy dominance of *Gilbertiodendron dewevrei* (*Caesalpiniaceae*), (6) Zone flooded almost all the year, with evergreen formations (e.g. 5b), raphiales and other hygrophylous formations, (7) Semi-deciduous forests, (8) Mangroves, (9) Various mountain formations, (10) Savannas, (11) Boundary of the area with Okoumé (from Brunck *et al.*, 1990 and unpublished data), (12) Current mean maximum extension of 'cooling' influences (according to Saint-Vil 1984), (13) Boundaries between States

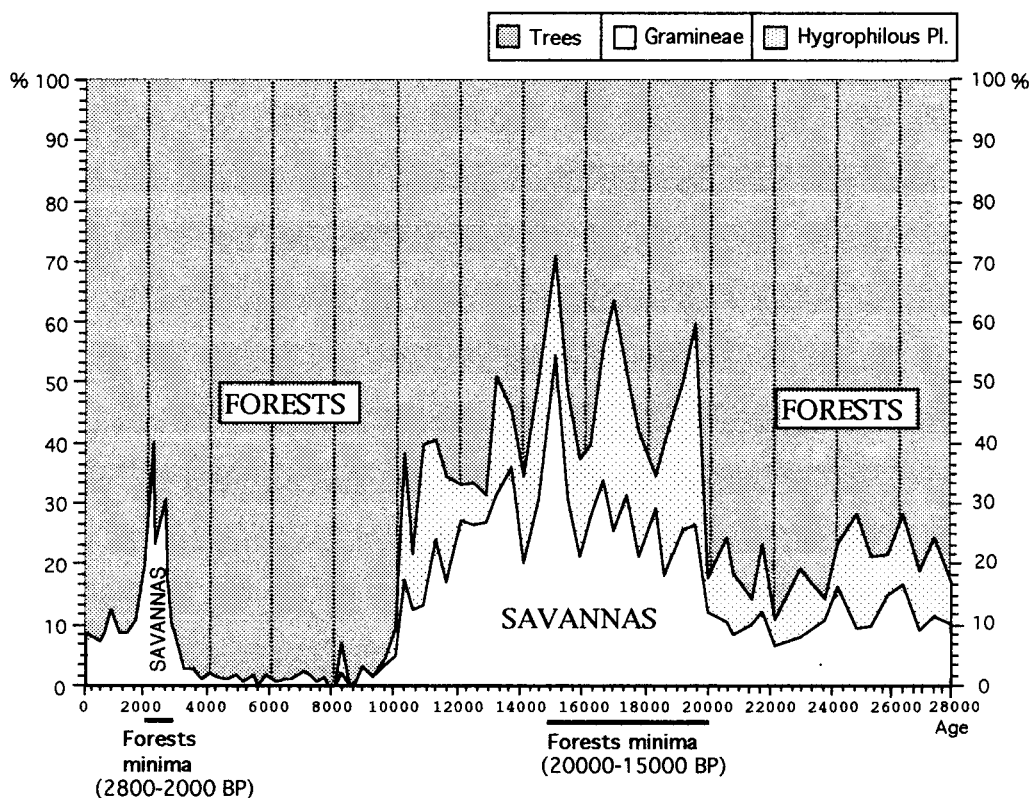


Figure 2: Site of Lake Barombi Mbo, altitude of ca. 300 m in the forests of west Cameroon. Synthetic pollen diagram (per cent) with an interpolated chronology based on 12 radiocarbon dates. Black dots represent total percentages of tree pollen; open area, total percentages of pollen from herbaceous plants, mainly *Gramineae*, and light dots the pollen percentages of *Cyperaceae*, hygrophilous plants linked to the lowering of the lake level.
Source: Maley and Brenac 1998a

minimum for all these variations in tree taxa occurred between 2500 and 2000 BP, during the major phase of destruction. The inverse – peaks of maximum extension – are not synchronous between taxa, with variations corresponding to long phases of sylvigensis, and the progressive, or abrupt replacement of taxonomic groups by others. Cycles of shorter duration (for example 1,000, 500 or 100 years) have not been shown to date, as the scale of sampling is insufficiently fine.² The pseudo-periods of 2,000 to 2,500 years can be related to climatic cycles of the same duration frequently observed across the globe, in particular during the Holocene, and to one of the dominant periodicities of solar activity, about 2,300 years (Magny 1993; Maley and Brenac 1998a).

2.1 The phase of forest destruction culminating about 2500 years BP

This phase of forest destruction (Figure 4) was general and synchronous, as can be deduced from both its abrupt occurrence between 3000 and 2500 years BP and its repeated discovery at every site studied in detail: in the northern part of the forest domain in west and south Cameroon at Barombi Mbo (Maley and Brenac 1998a), Mboandong (Richards 1986), Njupi (Zogning *et al.* 1997), and Ossa (Reynaud-Farrera *et al.* 1996; van Geel *et al.* 1998); in the southern part of the forest domain and in the Mayombe of western Congo at Kitina (Elenga *et al.* 1996), Kakamoeka (Maley and Giresse 1998), Songolo near to Pointe-Noire (Vincens *et al.* 1999), and at Ngamakala on

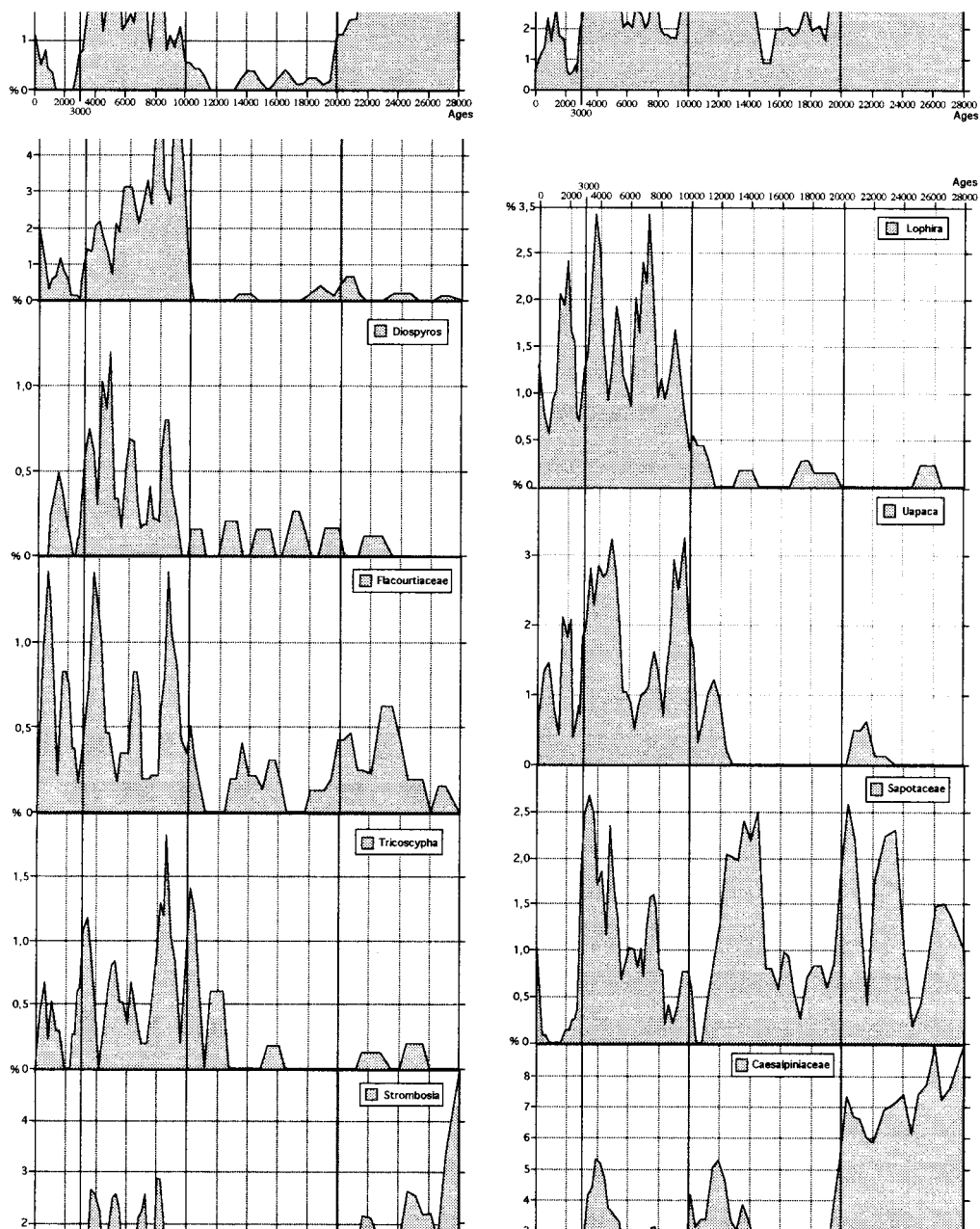


Figure 3a: Site of Lake Barombi Mbo, west Cameroon; percentages of diverse tree pollen.
 Typical tree taxa from mature forests
 Source: Maley and Brenac 1998a

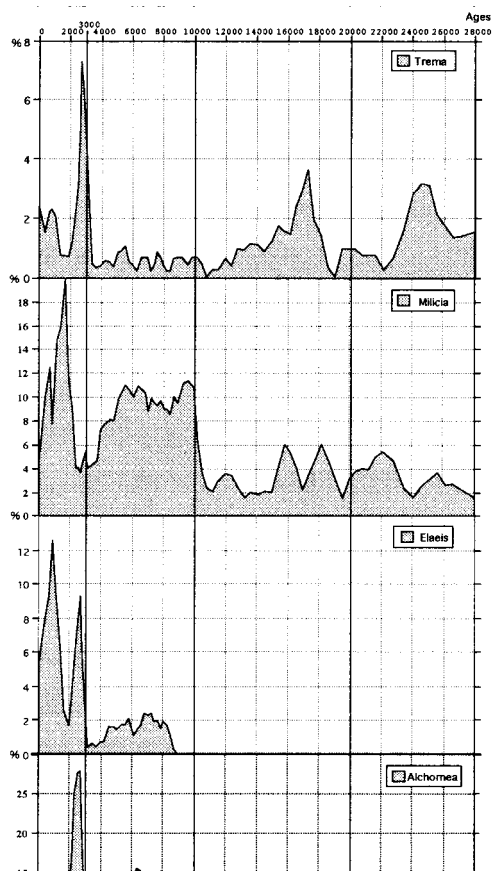


Figure 3b: Site of Lake Barombi Mbo, west Cameroon; percentages of diverse tree pollen. Typical tree taxa from pioneer forests
Source: Maley and Brenac 1998a

the Batéké Plateau (Eastern Congo) (Elenga *et al.* 1994). Where dating can properly frame the event, it dates more precisely to between 2800 and 2500 years BP.

During this phase, primary forest trees almost completely disappeared, and in certain sites (in west Cameroon at Barombi Mbo, Mboandong and Njupi, in south Congo and on the Batéké Plateau), there was a major expansion of savannas. This phase of forest destruction must have been very brief: in lacustrine strata where the abrupt and almost complete disappearance of primary type trees is observed, an 'explosion' of pioneer woody vegetation has been noted for some sites, such as at lake Barombi Mbo in west Cameroon (Maley and Brenac 1998a) (Figure 3b), at lake Kitina in the Mayombe, western Congo (Elenga *et al.* 1996), and at lake Ossa, south Cameroon (Reynaud-Farrera *et al.* 1996). The rapid expansion of pioneer trees must have been the first phase of 'scabbing', which initiated the reconstitution of the canopy. The most frequent pollen taxa are the pioneers *Alchornea cordifolia*, *Musanga*, *Trema*, *Macaranga*, *Elaeis guineensis*, etc. Although brief, destruction was intense, and several authors argue that the opening of the forest facilitated the major Bantu migration from areas presently north of the forest, to those now south of it (Schwartz 1992; Lavachery *et al.* 1996).

2.2 The reconstitution of the Central African forests during the last two millennia

Humid conditions favourable for forest returned earlier in west Cameroon, in particular at Barombi Mbo, dating from 2000 years BP. Yet the reconstitution, especially of 'primary' type forests, was not synchronous, and probably reflects the distribution of the residual forests (Figure 4). The delay can be understood in terms of 'hysteresis' (Maley and Brenac 1998a).

The reinvasion of savanna by forest continued during the twentieth century, as observed over much of the forest-savanna transition region. This is evidenced by the comparison of air and satellite photographs of different dates from the 1950s to the present (see Blanc-Pamard and Peltre 1984; Maley 1990, 1996; Fairhead and Leach 1995,

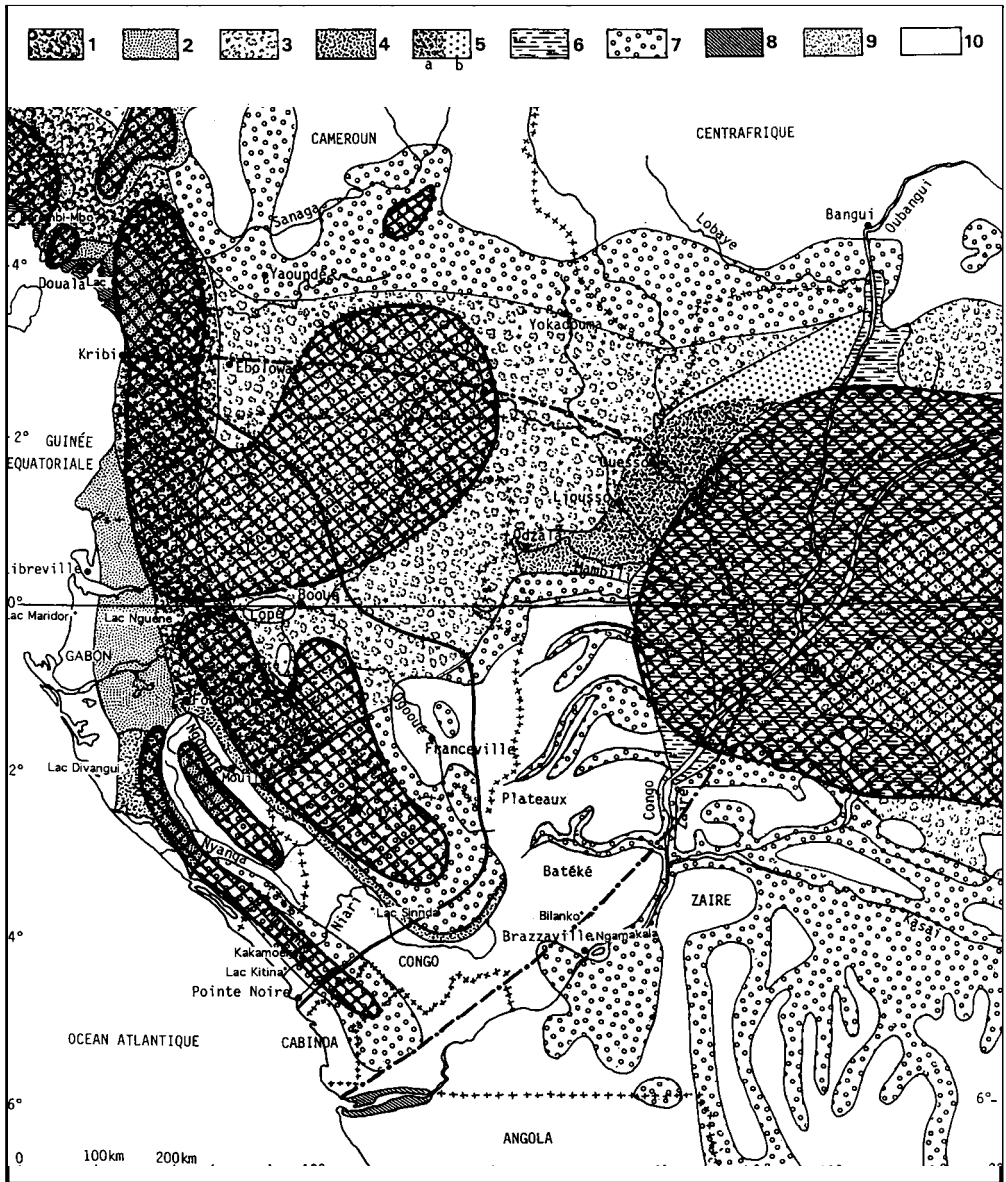


Figure 4: Schematic drawing of the status of Central African vegetation at the phase of maximum perturbation and destruction of forest, which culminated around 2500 BP

Large hatched areas represent the residual areas of the forest domain around 2500 BP, which probably consisted of forest-savanna mosaic with predominantly larger forest islands. Around these residual areas the land would have been colonised by open vegetation, above all savannas, but also open canopy forest formations (see (4) in Figure 1). The base of this map presents the current status of Central African biotopes, as in Figure 1

1998; Servant 1996). For south Cameroon alone (south of the Adamaoua Plateau), forest gained about a million hectares during this period (Letouzey 1985; Youta Happi and Bonvallot 1996; Achoundong *et al.* 2000). Historical and palynological research in Côte d'Ivoire, Nigeria, Cameroon, and Congo indicate that this reinvasion has continued over several centuries (Fairhead and Leach 1998; Maley 1999; Vincens *et al.* 2000). Albeit with fluctuations and interludes, it appears to be the continuation of the forest reinvasion which began about 2000 years BP. Current reinvasion is thus the long-term result of the massive forest disturbance which happened around 2500 years BP.

A brief review of research findings concerning oil palm and Okoumé can illustrate the history of these forest ecosystems over recent millennia.

3 The history of oil palm and of Okoumé in Central Africa during the Holocene: impact of the forest disturbance culminating about 2500 years BP

3.1 The oil palm

Oil palm (*Elaeis guineensis*) has abundant and characteristic pollen, and thus appears frequently in sedimented pollen profiles. This palm is of African origin, with its pollen and macro-remains (nuts) found in Equatorial African deposits dating back to the Tertiary (Zeven 1967; Dechamps *et al.* 1992; Maley 1996, 1999; Maley and Brenac 1998a; Maley and Chepstow-Lusty 2001).

The extent to which oil palm has been planted or its regeneration encouraged through land use has been debated. Certainly when people clear young pioneer forests or fallows near to villages, where oil palm is naturally abundant, they generally conserve the palms, effectively enriching them through fallow cycles (e.g. in Cameroon, Central African Republic, Côte d'Ivoire, Togo and Benin; see Maley 1999). Thus, in 1937, the renowned botanist Aubréville, characterised the 'immense oil palm groves' of southern Benin as 'a natural formation, simply improved by the inhabitants over the centuries'. Zeven's research, largely from Nigeria, also concludes that with the exception of

modern industrial plantations, most oil palms in Africa are semi-wild, and are not propagated by sowing or transplanting seedlings (see Zeven 1972).

Ecologically, oil palm is a pioneer that requires light to complete the first stages of its growth, so it develops naturally in windfall-clearings and especially on the periphery of dense forest after the passage of fire which it can tolerate (Swaine and Hall 1986; Swaine 1992). The botanist Letouzey (1978, 1985) has described a vast natural oil palm grove in west Cameroon and near the north-west of the forest zone (Figure 5). A band of forest 10–20 km wide, dominated by large and numerous oil palms extends over more than 150 km. This follows the boundary between forest and savanna, at times from 5 to 30 km inside the forest. From the absence of trees classically found in anthropic plantations, and other criteria Letouzey (1978, 1985) concluded that this grove is a natural stand. A similar example has been described on the eastern flank of Mount Nimba (Guinea/Liberian border) by Schnell (1946) who considered that the dissemination of palm nuts was facilitated by both toucans and chimpanzees, whose faeces often contain it abundantly. These natural groves have attracted migrant people (e.g. Guille-Escuret 1990; Maley 1999). For example, many Bamileke people moved to the natural groves of western Cameroon in the mid nineteenth century (Barbier 1981; Warnier 1985; Perrois and Notue 1997; Maley 1999). In the vast 'Grassfields' just north of west Cameroon's forest bloc, the forest islands are still in a phase of expansion, especially due to the oil palm which is one of the principal pioneer trees. Close to the Donga river the Wuli people colonised these natural stands. Baeke (1996) explains how the Wuli install their villages in the palm groves, where assorted social rules oppose all plantation of palms. Moreover, she reports that a Wuli myth of origin 'provides evidence for the prior use of oil palms to the working of land and clearly distinguishes two types of plant exploitation; gathering and agriculture' (Baeke 1996).

As already noted, during the major disturbance about 2500 BP, oil palm was a principal pioneer that subsequently developed strongly (Figure 3b). In west Cameroon, the rapid forest recolonisation, which occurred from 2,000 years ago in the

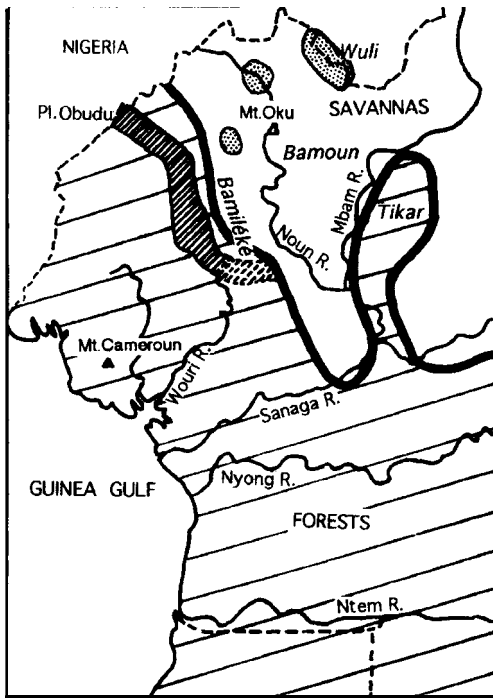




Figure 5: An 'oil palm belt' near the edge of the rain forest in west Cameroon

 Belt with a high density of *Elaeis guineensis* (oil palm) reaching 20 to 25 m height in association with a mature forest of the semi-deciduous type.

 In the Grass Fields, extensive savannas north of the forest, pioneer forest islands with large concentrations of oil palms. In italics, the names of some important groups of people (*Bamileke*, *Bamoun*, *Tikar*, *Wuli*)

Source: adapted from Letouzey 1978 and 1985

vicinity of Barombi Mbo (Maley and Brenac 1998a), was accompanied by a retreat of oil palm, probably because ecological and climatic factors rendered other pioneers more active at this time. In Figure 3 it is notable that in west Cameroon, between 2000 and 1000 years BP, the pioneer tree *Milicia* was in a phase of very strong expansion. Then here and elsewhere in central Africa, a second phase of oil palm expansion began around 1400 years BP. This culminated towards 1000 BP at lake Ossa near to Edea (Reynaud-Farrera *et al.* 1996), in the south of the Central African Republic at Nouabale-Ndoki (Fay 1997; Maley 1999) but also

further south in Gabon to La Lopé (White *et al.* 2000; Maley, unpublished) and in western Congo near to lake Kitina (Elenga *et al.* 1996). This phase, ending about 700/800 BP, must have been associated with renewed forest disturbance, but weaker than that 2500 BP. This disturbance was also associated with a short phase of soil erosion and with a discontinuity in the deposits observed in assorted locations in Central Africa (Maley and Brenac 1998b). An increase in mineral fluxes has been found between 1200–800 years BP for the sites of Kitina and Sinnda in western Congo (Bertaux *et al.* 2000). From the thirteenth century, a phase of forest recovery has occurred in Central Africa, with a new development of mature forests and a generalised retreat of oil palm; a recovery despite increased human settlements (Alexandre 1965; Vansina 1990).

At the western extension of the Central African forests lies a large area without forest which biogeographers call the Dahomey Gap, stretching across southern Togo and Benin. Much of this is covered by an immense palm forest of natural origin, as it was described by Aubréville (1937) and Mondjannagni (1969). Some pollen data show that this area was covered by forests during the early and mid Holocene (Dupont and Weinelt 1996) and that the opening-up of the landscape occurred rather abruptly between 4000 and 3500 BP following a climatic change well-documented for the neighbouring region of Ghana, at lake Bosumtwi (Maley 1991, 1997, 1999). Moreover, it appears that the break in the forest bloc was originally much wider than it is now, perhaps extending across almost all of south-west Nigeria up to the Niger river. Indeed, from the beginning of the last millennium to the sixteenth century AD, some data show that this vast sector was not forested but becoming so (Barber 1985) and that the vegetation was dominated by oil palm, appearing similar to currently existing vegetation across southern Benin and Togo. Data indicating this exist for an area near to the ancient city of Benin (Okomu Forest, about 100 km west of the Niger river), suggesting also that the forest extension occurred only in recent centuries (Jones 1956; White and Oates 1999). Further research will be necessary to clarify these various points and their precise chronology.

3.2 Okoumé

Okoumé (*Aucoumea Klaineana*, *Burseraceae*) is currently restricted to the west and centre of Gabon, with a limited extension in the south-west of Congo and another towards the north in Equatorial Guinea (Brunck *et al.* 1990) (Figure 1). Like oil palm, Okoumé is a light demanding, pioneer species (which for some ecological reason appears unable to live outside of central Africa; Brunck *et al.* 1990; Maley 1990; Nasi 1997). In its area, this tree is perfectly adapted to colonise pioneer forest fronts as they progress into savannas, and often dominates them (Nasi 1997; White *et al.* 2000). It is abundant in fallows and along forest tracks. As pioneer fronts mature and age, other trees of shade-tolerant species appear (e.g. *Caesalpinaceae*) and the Okoumé which survive are the dispersed individuals whose crowns have already reached the canopy, living to 100–150 years and achieving 1.2 m diameters (Nasi 1997). It can be deduced that the large Okoumé currently present in the forest interior in its natural range, were born in contact with savannas.

The endemism of Okoumé, with its range limited mainly to Gabon, is linked to its history and its ecology. It is intolerant of water deficit and thus of the elevated temperatures of the long dry seasons (about 3 months, from December to February) of tropical climates. Within its Gabonese range, water deficit is less severe than in neighbouring southern Cameroon, because the equatorial climate's dry season (mostly from June to August) retains the elevated air humidity and moderate temperatures (Brunck *et al.* 1990; Maley 1990).

Several works bring important precision to the history of Okoumé. First, palynological data obtained in south Cameroon at lake Ossa near to Edea (Reynaud-Farrera *et al.* 1996) show that between 7500 and 3000 BP (middle Holocene) the distribution of Okoumé extended much further north, reaching the lake about 170 km north of the tree's present range, and perhaps further east and further south in western Congo. Second, molecular genetics show two completely distinct varieties of Okoumé, one to the north of its range, and another to the south (Muloko *et al.* 1998, 2000). The boundary between the ranges runs approximately east-west, a little to the south of the equator, towards 0°40'South.

It can be deduced that the current range of Okoumé has resulted from the fragmentation of a large ancient range dating back to the middle Holocene, fragmented by the generalised forest disturbance about 2500 BP into two very dispersed sub-groups, one to the south and the other to the north. The extension of open landscapes during the period of destruction would have been favourable to Okoumé's new phase of development, in a similar way to that evidenced at Barombi Mbo for several other pioneer trees (Figure 3b). The general forest recolonisation, dating from about 2000 BP, was in an extremely fragmented environment with numerous ecotones favourable to the development of Okoumé. It is thus likely that the current range of Okoumé is about 2,000 years old at most.

A dynamic model, which nearly follows this chronological canvas, has been established by White (1995). This is based on examination of the current vegetation of the northern part of the La Lopé reserve, which is situated at the heart of the Gabon's forest and still holds large patches of residual savanna (see Aubréville 1967). White (1995) shows how the forest reconstituted itself progressively thanks to the wide bands of pioneer forest rich in Okoumé which surround these savannas. The progression of pioneer forest fronts can be blocked by savanna fires, often of anthropic origin (Oslisly and White 2000). Even so, over the long term from about 2,000 years ago, the continuous general trend has been in favour of reforestation.

That the current and expanding range of Okoumé has not extended much into south Cameroon, as had been the case in the middle Holocene, is probably explained by a shift in climatic conditions between this older period and the recent (post-2000 BP) Holocene. This deduction is important as, given the ecological particularities of Okoumé which link it tightly to the equatorial climate, one can further deduce that equatorial climates must have reigned over south Cameroon during the middle Holocene. The present tropical climate there thus dates from only about 2000 BP. All this appears to translate, for the middle Holocene, into an increase in 'southern' equatorial influences towards the north, associated with a reduction in 'northern' boreal influences, and possibly linked to a reduction in the length of the dry season associated with the boreal winter.

4 The question of savanna fires, and the extension of the forest disturbance in eastern Congo

Observations and opinions have frequently diverged concerning the influence of savanna fires on contemporary forest regeneration. Observers variously report that fire can either prevent regeneration, as in the area of savanna inliers in Lopé, Gabon (Oslisly and White 2000), or merely delay it, as in other parts of the forest region. Thus Letouzey (1968) notes for the forest-savanna transition zone of south Cameroon that 'fire does not necessarily prevent the formation of forest recovery'. Similar conclusions have been drawn in Central Africa by Sillans and even in western Congo (ex-Zaire) for the south of the forest bloc (Letouzey 1968). On the same lines, Youta Happi and Bonvallot (1996) report 'that on the periphery of a town of 76,000 people such as Bertoua (east Cameroon) many small savanna inlets into forest, of two to ten hectares, have become covered by forest regrowth despite the annual bush fires practiced by Bororo pastoralists'. A little further south, in the Odzala Reserve situated at the northern extremity of the Bateke savannas (north Congo), Dowsett-Lemaire reports that: 'Without doubt, one is in a phase of forest extension despite very frequent bush fires' (1996). This author notes 'the fire-break role of the boundary thanks to groves dominated by *Gaertnera paniculata*; a species absent at Lopé where colonising species are apparently more sensitive to fire.' Thus the floristic composition of the boundary plays an important role in this phenomenon. This was shown in south-east Cameroon by the mid-twentieth century invasion of *Chromolaena odorata*, which colonised the boundaries and which acts, there at least, as an efficacious fire break. It also protects seeds of woody species, which can germinate and develop under its cover (Youta Happi *et al.* 2000). Other observations show how traditional agricultural practices and the movement of cattle can be favourable to forest recolonisation, in particular by eliminating the grasses, which facilitate the propagation and intensity of fires. These processes have been well described in southern Cameroon (Letouzey 1968, 1985) and in Côte d'Ivoire (Spichiger and Blanc-Pamard 1973; Blanc-Pamard and Peltre 1984; Gautier 1990).

These observations indicate that in general, and especially over the long term, forest colonisation at the forest-savanna contact has been the broadly dominant process. In certain exceptional years when the dry season has been one or two months longer, the savanna fires have penetrated more deeply into the neighbouring forests. In early 1983, during a two-month longer dry season, numerous observers reported the strong invasion of fire into forest in Côte d'Ivoire (Bertault 1990), Ghana (Hawthorne 1991; Swaine 1992) and Cameroon (Amougou 1986). Equally, fires in Indonesia that year were linked to an exceptional El Niño event (Goldammer and Seibert 1990).

These observations indicate how the penetration of fire into forest occurs only in very dry years. One might thus think that fires could have played a major role in the forest destruction 2500 BP. This has, indeed, been shown in eastern Brazilian Amazonia during its major disturbance in the middle Holocene. That fires were frequent then is shown by the numerous charcoal fragments deposited in the lake sediments at Carajas (Martin *et al.* 1993; Servant *et al.* 1993). Yet the late Holocene lake deposits in Central Africa hardly contain any charcoal fragments, especially for the period 3000–2000 BP (Giresse *et al.* 1994; Maley and Brenac 1998a; Bertaux *et al.* 2000). It is the same for the upper horizons of the numerous soil profiles observed in this region (e.g. Vallée 1973). In the thalwegs, the coarse deposits in the lower part of the Lower Terrace do at times contain charcoal or fragments of fossil wood (Maley and Brenac 1998b), however. Iron age archaeological sites dating from the beginning of the late Holocene, such as in the savanna areas of La Lopé, also present wood charcoal (Oslisly and White 2000). One can conclude provisionally that the fires that existed were of limited extent.

In particular, charcoal associated with iron smelting furnaces cannot have caused the forest disturbance, and cannot have been responsible for the savanna extension about 2500 BP. Goucher (1981) had advanced the hypothesis that iron smelting could have been a major cause of deforestation in West Africa, but Fairhead and Leach (1998) have demonstrated that this hypothesis had no serious foundation. For Central Africa Pinçon (1990) also concludes that the

extraction of wood for iron metallurgy on the Bateke Plateaux was minimal and did not explain (as had been suggested) the presence of the extensive savannas there. Instead, these savannas result from an elevated edaphic drought caused by very sandy soils in which rain infiltrates rapidly to a great depth (Laraque and Pandi 1996).

In contrast to observations from Atlantic Central Africa (south Cameroon, Gabon and Congo), wood charcoal has been found in abundance in Ituri near to Epulu (c. 1°20'N–28°35'E). Here, in the heart of the forests of the north-east Congo basin about 180 km from the nearest savannas, 416 soil profiles have been examined. Almost all of them contain numerous wood charcoal in their upper levels, between the surface and 50 cm deep (Hart *et al.* 1996). Virtually all of the 1,817 samples of wood charcoal identified by Deschamps belong to trees found in the region's diverse forest formations, except for a few pieces of charcoal from two profiles, which belong to typical wooded savanna species. The 28 dates obtained for the charcoal show that fires occurred almost exclusively during the last three millennia, with a phase of wooded savanna expansion dating to about 2200 BP (Hart *et al.* 1996). Moreover, about 300 km south of Epulu, and 100 km from the forest/savanna limit, a road cutting near Osokari (1°16'S–27°48'E), revealed a remarkable profile above the principal stone line that could be dated to about 11,500 years BP (Runge 1996; Maley 1996). A second gravel level, obliquely cutting the top of the soil profile contains wood charcoal dating from about 2200 to 1850 BP. These results show that the forest disturbance in Atlantic Central Africa extended to Ituri and affected a large part of the eastern region of the Congo river basin. In contrast with regions nearer the Atlantic, fire had a large role.

Also at Ituri (Epulu), Hart *et al.* (1996) show that certain trees which are now found there are not found in the wood charcoal, in particular *Gilbertiodendron dewevrei* (*Caesalpinaceae*) which is now abundant (almost mono-dominant) in certain parts of the forest. The range of forests dominated by *Gilbertiodendron dewevrei* extends to the east and north of the Congo basin, as far as east Cameroon (Léonard 1953). It is thus possible that this *Caesalpinaceae* has very recently colonised the Ituri forests, and that the large area it now occupies is a

legacy of the disturbance about 2500 BP. If confirmed, this area could correspond, at least partly, to an older forest area (of unknown character) which was destroyed by the disturbance. A comparison with Okoumé can be suggested which, as indicated for Gabon above, also dominates areas which it has colonised since, less than 2,000 years ago. However, as the forest ages, Okoumé loses its dominant character, whereas in Ituri *Gilbertiodendron dewevrei* remains dominant, probably because it can regenerate abundantly in the shade of parent trees, and also because its reproductive character gives it an advantage over other trees in this formation (see Hart 2001).

5 Conclusion: the major role of climatic conditions and their history

The present mosaic pattern of numerous forests, characterised by a mix or juxtaposition of groupings of evergreen and deciduous species, is probably the consequence of long-term disturbances which have affected the forest domain during the last three millennia, particularly the major disturbance which culminated about 2500 years BP. The synchronism apparent in the disturbance for different sites studied across Central Africa (south Cameroon, Gabon, Congo as far east as the Congo River basin) and its association with a generalised erosive phase enables one to conclude that it was the result of a major climatic change.

The climate at this time appears to have been relatively arid as it led to forest destruction and, in places, the extension of savannas. Nevertheless, other characteristics, such as the strong synchronous extension of diverse pioneer taxa, indicate that in places there was not truly a reduction in rainfall but rather a change in its annual distribution. The absence of a fall in annual rainfall has been demonstrated at lake Barombi Mbo (Maley and Brenac 1998a) and at lake Ossa, where diatom studies show that there was even a net rise in this lake between 2500 and 2200 years BP, with only a short fall between 2200 and 2000 years BP (Nguetsop *et al.* 2000). It is therefore preferable to designate this catastrophic period as an 'unfavourable climatic disturbance' caused by an increase in seasonality and a lengthening of the dry season (Maley 1997). The strong soil erosion of this

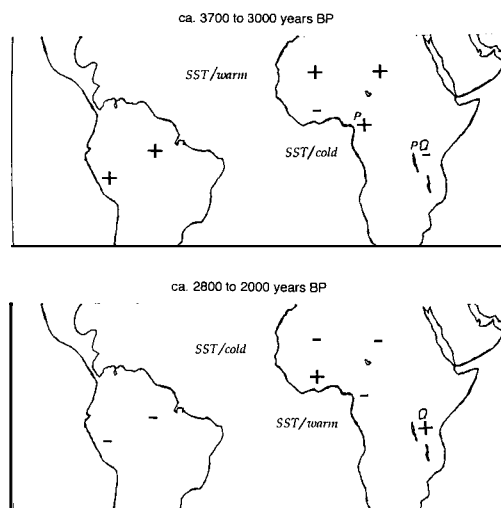


Figure 6: Major rainfall trends in tropical Africa and South America for two opposed climatic periods, c. 3700–3000 BP and c. 2800/2500–2000 BP

Precipitation trends: (anomalies) above normal/mean +; below normal/mean –; P points to the sectors where a maximum of *Podocarpus* pollen intervened

Source: Maley 1997; Maley *et al.* 2000

period suggests heavy rains, but concentrated over six or seven months of the year, as is now found in the peripheral savanna zones. The growth in seasonality could have been associated with a dominance of ‘squall lines’, the typical cloud formation of savanna zones, formed by north/south alignments of cumuliform (convective, storm-type) clouds. They supplanted other cloud types, principally the stratiform types which give relatively fine, regular monsoon-type rains (see Maley 1982). That these monsoon rains would have dominated the earlier period (between 4000 and 3000/2800 BP, Maley 1997), is shown by the relative development of *Caesalpinaceae* in the forests of low altitude and, in the mountains, by the extension of *Podocarpus* which are trees typical of cloud forests, with stratiform clouds (Kerfoot 1968; Maley 1996, 1997; Maley and Brenac 1998a).

Research in dynamic tropical climatology over the last 20 years shows that Sea Surface Temperature (SST) on the regional and global scale strongly influences climate (Fontaine and Bigot 1993;

Moron *et al.* 1995; Bigot *et al.* 1997). It is possible to characterise the relations between the monsoon rains and the SST more precisely. Studies of climatic anomalies over tropical Africa occurring since the beginning of the 1960s have evidenced two dominant modes of rainfall distribution, each associated with a particular distribution of SST. The first mode is characterised, on the one hand by warmer than average temperatures in the Gulf of Guinea and the southern Atlantic, and on the other hand, by cooler temperatures on the north tropical Atlantic, offshore of West Africa. The second mode presents an opposed distribution for the African continent and the ocean. A north-south tropical Atlantic ‘dipole’ has thus been found which oscillates between one mode and the other (Fontaine and Bigot 1993; Wotling *et al.* 1995; Bigot *et al.* 1997). An important research result has been to show that over recent millennia the spatial distribution of paleo-climatic anomalies over tropical Africa (more humid regions and more dry ones; Figure 6) and of SST on the neighbouring Atlantic, is very similar to the spatial distribution observed for the two dominant anomalies over the last four decades (Maley 1997; Maley *et al.* 2000). One can deduce that the climatic mechanisms are the same at the timescale of years, centuries or millennia.

So the variation of SST over the tropical Atlantic appears to play a major role in the variation of climate and rain types over Central Africa. The phase of forest disturbance that culminated about 2500 years BP was associated with relatively ‘warm’ SST over the Gulf of Guinea. The earlier phase between about 4000/3800 and 2800 years BP was associated with relatively ‘cool’ SST, sharply reduced from the early and middle Holocene (see Morley and Dworetzky 1993; Figure 7). Over west and south Cameroon these SST allowed relatively high rains and the evolution of stratiform clouds towards rainy nimbostratus types. The palaeovegetation data are presently lacking for Gabon. However, new research is underway within the PALEOFORGA (Paleoenvironments of Gabon Forests) programme, studying lakes Maridor, Nguène and Kamalété (Figure 1). In contrast further south, in western Congo, the period starting from 5000 years BP (Bertaux *et al.* 2000) was marked by the development of semi-deciduous forests (Vincens *et al.* 2000) linked to lower

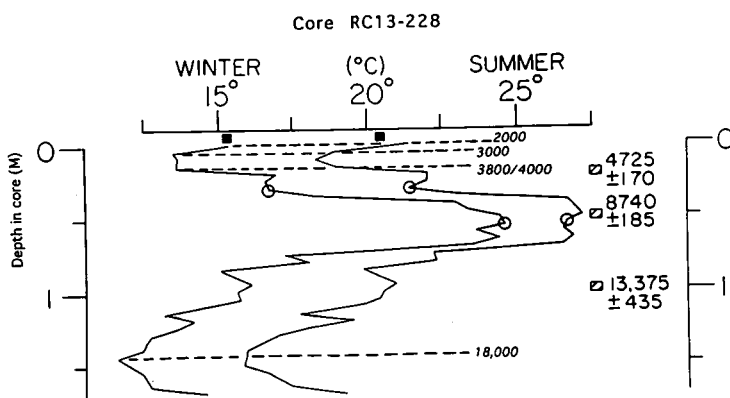


Figure 7: Variations in Sea Surface Temperature (SST) in the South Atlantic Ocean, Benguela sector (22°0'S–11°12'E), estimated with transfer functions based on the abundance of Radiolarian species in the core RC13–228

The open circles designate the 6000 and 9000 BP interpolated dates for the two curves, one corresponding to the southern summer (February) and the other to the southern winter (August); modern SST are indicated by the solid squares above each curve. The dashed lines represent some interpolated dates (italics): 18 000 BP, based on the oxygen-isotope stratigraphy; 3800/4000 BP, 3000 BP and 2000 BP. These late Holocene dates are confirmed by an independent study of shells from the same sector (Cohen *et al.* 1992). The coherence of the main SST anomalies throughout the Guinea Gulf permits the use of these curves in order to interpret the paleoclimatology of central Africa (Maley 1997)

Source: Morley and Dworetzky 1993

rainfalls, indicating that the stratiform clouds had probably evolved towards non-rainy clouds. The four-month dry season here is characterised by the quasi-permanence of these cloud types (Saint Vil 1984), which probably gained place progressively between 5000 and 4000 years BP. There was therefore a reinforcing of southern influence, supporting conclusions concerning the history of Okoumé. It is notable that the vegetational impacts of the 'warm' SST c. 2800/2500 to 2000 years BP were very different from those earlier, c. 9000 to 6500/6000 years BP; a difference which reflects a brutal strengthening over Central Africa of boreal influences (Nguetsop *et al.* 2000), to the detriment of southern influences, from about 2800/2500 years BP.

Before the major Holocene forest disturbance culminating about 2500 BP, other important disturbances occurred during the Quaternary (Maley 1996). The best documented is that between about 20 000 and 15 000 years BP (Maley 1987, 1996; Maley and Brenac 1998a; Figure 2). In both cases, residual forest environments (refugia)

persisted, apparently in similar locations, but perhaps less as small blocks of relatively homogeneous forest than as a landscape of forest-savanna mosaic in which forest islands dominated (see Leal 2000). Yet two important characteristics clearly differentiate these two phases of forest fragmentation. First, the older disturbance was much longer. Second, they occurred under very different (even opposed) general climatic conditions. The disturbance between 20 000 and 15 000 BP coincided with the development of glacial conditions in middle and high latitudes, and cooler conditions by several degrees also affected the whole region of the Gulf of Guinea (Maley 1996; Maley and Brenac 1998a). The most recent disturbance, by contrast, occurred during the Holocene interglacial which on a global scale, is characterised by reduced glacial extension and relatively warmer temperatures. The period between 2500 and 2000 BP is associated with slightly warmer climatic conditions on the regional and global scale (Maley 1997; Maley *et al.* 2000). An important conclusion is that the retreat and fragmentation of the African forests can be produced under very different

climates, either relatively cool or relatively warm, and thus with very different climatic situations (Maley 1996, 1997).

Climatic models concerning 'global warming' in the context of contemporary climate change concerns indicate that an average growth in temperature of about 4°C will lead also to an increase in evaporation of about 30 per cent, but only 12 per cent more rain for tropical Africa (Rind

1995). Though the causes of warming experienced about 2500 years BP were natural (Magny 1993) and therefore different from the warming envisaged for the twenty-first century, it is possible that the catastrophic destruction of Central African forests which culminated about 2500 years BP could be an 'analogue' and an alarm signal for potential developments during this current and future phase of human-induced global warming (Maley 1997; Maley *et al.* 2000).

Notes

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